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Request for grant of a patent

The Patent Office
Cardiff Road
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1. Your reference
1861601/AM

- 5 MAR 2002

2. Patent Application Number **0205116.7**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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Patents ADP number *(if known)* 7866809002

If the applicant is a corporate body, give the country/state of its incorporation

Country: **England**
State:

4. Title of the invention

POSITION SENSOR

5. Name of agent

"Address for Service" in the United Kingdom to which all correspondence should be sent

Patents ADP number

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6. Priority details

Country	Priority application number	Date of filing

Patents Form 1/77

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier application Date of filing

8. Is a statement of inventorship and or right to grant of a patent required in support of this request?

Yes

9. Enter the number of sheets for any of the following items you are filing with this form.

0	Continuation sheets of this form
32	Description
7	Claim(s)
1	Abstract
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0	Priority documents
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1 + 1 copy	Statement of inventorship and right to grant of a patent *(Patents form 7/77)*
0	Request for preliminary examination and search *(Patents Form 9/77)*
0	Request for Substantive Examination *(Patents Form 10/77)*
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11. I/We request the grant of a patent on the basis of this application

Signature Beresford & Co Date 5 March 2002

BERESFORD & Co

12. Name and daytime telephone number of person to contact in the United Kingdom

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POSITION SENSOR

The present invention relates to a position sensor and to parts therefor. The invention has particular although not exclusive relevance to the design of windings used in an inductive position sensor. The invention can be used in one, two or three dimensional position sensors. The sensor is particularly useful for embedding behind the display of a hand-held electronic device such as a personal digital assistant (PDA), mobile telephone, web browser or products embodying combinations of these.

Many types of non-contact linear and rotary position sensors have been proposed for generating signals indicative of the position of two relatively movable members. Typically, one of the members carries one or more sensor windings and the other carries one or more magnetic field generators. The magnetic field generators and the sensor windings are arranged such that the amount of magnetic coupling between the magnetic field generators and the sensor windings varies as a function of the relative position of the two members.

In some of these non-contact position sensors, the sensor windings and the magnetic field generators are designed

to try to make the output signal vary linearly with the relative position between the two members, since this reduces complexity of the signal processing required to determine the positional information. However, it is difficult to design a system which is exactly linear and they are usually relatively sensitive to variations in the gap between the sensor windings and the magnetic field generator.

In other systems, the sensor windings and the magnetic field generator are arranged so that the output signal from the sensor windings varies approximately sinusoidally as a function of the relative position of the two relatively movable members. A particular design of such "sinusoidal" sensor windings is disclosed in the applicants' earlier international application WO 00/33244. Two of these "sinusoidal" type sensor windings are provided which are physically offset from each other so that phase quadrature output signals are provided, from which the position information can be obtained using an arc tangent function.

To date, the design of each sensor winding has been made independently of the design of the other sensor winding(s), with the aim being to maximise the

"sinusoidal" nature of each winding independently. The inventor has realised that this design approach is flawed since it is almost impossible to design each sensor winding so that it will provide a perfect sinusoidal response over the desired measurement range. Consequently, the inventor has realised that the design of the sensor windings should be considered together so that imperfections in the required response characteristic of one sensor winding can be cancelled out by corresponding imperfections in the response characteristic(s) of the other sensor winding(s).

Various features and aspects of the present invention will become apparent from the following description of exemplary embodiments which are described with reference to the accompanying drawings in which:

Figure 1 is a schematic view of a hand-held personal digital assistant (PDA) which includes an x-y digitising system located behind the PDA's liquid crystal display which can sense the (x,y) position of a resonant stylus;

Figure 2 schematically illustrates a cross-sectional view of the personal digital assistant shown in Figure 1, illustrating the positional relationship between a sensor

printed circuit board of the digitising system and the liquid crystal display;

Figure 3 is a schematic functional block diagram illustrating the excitation and processing electronics of the x-y digitising system and illustrating the magnetic coupling between an excitation winding of the digitising system and the resonant stylus and the magnetic coupling between the resonant stylus and four sensor windings which form part of the digitising system;

Figure 4a schematically illustrates an approximation of the way in which the peak amplitude of the signals induced in x-sensor windings of the digitising system vary with the x-coordinate of the position of the stylus relative to the liquid crystal display;

Figure 4b schematically illustrates an approximation of the way in which the peak amplitude of the signals induced in y-sensor windings of the digitising system vary with the y-coordinate of the position of the stylus relative to the liquid crystal display;

Figure 5a illustrates the form of a sin x sensor winding of the digitising system which forms part of the personal

digital assistant shown in Figure 1;

Figure 5b illustrates the form of a cos x sensor winding of the digitising system which forms part of the personal digital assistant shown in Figure 1;

Figure 5c illustrates the form of a sin y sensor winding of the digitising system which forms part of the personal digital assistant shown in Figure 1;

Figure 5d illustrates the form of a cos y sensor winding of the digitising system which forms part of the personal digital assistant shown in Figure 1;

Figure 5e shows a top layer of a printed circuit board which carries the windings shown in Figures 5a to 5d;

Figure 5f shows a bottom layer of the printed circuit board which carries the windings shown in Figures 5a to 5d;

Figure 6 is a cross-sectional view of the resonant stylus shown in Figure 1; and

Figure 7 is a perspective view showing a mobile telephone

having a liquid crystal display and a digitising system under the display which is operable to sense the position of a resonant stylus relative to the display.

Overview of Digitising System

Figure 1 shows a hand-held, battery-powered personal digital assistant (PDA) 1 which employs an x-y digitising system (not shown) which is located beneath a liquid crystal display 3 of the PDA 1. The x-y digitising system is operable to detect the presence and x-y position of a resonant stylus 5 relative to the LCD 3. The position signals output from the digitising system are used by the PDA 1 to control information that is displayed on the LCD 3 and to control the operating function of the PDA 1. As shown, the PDA 1 also includes a number of push buttons beneath the LCD 3 including an on-off button 7 and a number of control buttons 9-1 to 9-4 which are used to control different functions of the PDA 1.

Figure 2 shows a cross-sectional view on A-A of the PDA 1 shown in Figure 1. As shown, the PDA 1 includes a liquid crystal display 3 which, in this embodiment, is between 1.5mm and 3mm thick. Beneath the LCD 3, there is an electroluminescent backlight 11 for providing a

backlight for the LCD 3. In this embodiment, this backlight layer 11 has a thickness of approximately 150μm. Beneath these layers, there is a 0.2mm thick sensor printed circuit board (PCB) 13 which forms part of the above-mentioned x-y digitising system. This sensor PCB 13 carries the excitation winding and the sensor windings used for sending signals to and receiving signals from the resonant stylus 5. Beneath the sensor PCB 13 there is a printed circuit board 15 which carries the electronics for controlling the functions of the PDA and the digitiser electronics for processing the signals received from and controlling the signals sent to the windings on the sensor PCB 13.

As shown in Figure 2, in this embodiment, a grounded electrostatic screen 17 is provided between the sensor printed circuit board 13 and the electroluminescent backlight 11 in order to reduce noise from the liquid crystal display 3 and the backlight 11 from interfering with the x-y digitising system. In this embodiment, this electrostatic screen is formed from a continuous layer of carbon ink which is approximately 10μm thick and has a relatively high surface resistivity (e.g. > 1 ohm per square) so that it does not interfere with the magnetic sensing function. Further, as shown in Figure 2, beneath

the sensor PCB 13 is a 50μm layer of pressure sensitive adhesive 19 for bonding the sensor PCB 13 onto a magnetic screen 21, which in this embodiment is a 25μm layer of spin melt ribbon (for example Vitrovac 6025 manufactured by Vacuumschmelze, Hanau, Germany). As those skilled in the art will appreciate, the magnetic screen 21 is provided in order to reduce any disturbance which may be caused to the x-y digitising system by, for example, the electronics behind the sensor PCB 13. It also enhances the sensitivity of the x-y digitising system since it provides a permeable path for magnetic flux to pass behind the sensor windings on the sensor PCB 13. As shown in Figure 2, encasing these layers and providing mechanical support is an outer casing 23 which is made, in this embodiment, from plastic.

Figure 3 schematically illustrates a functional block diagram of the digitising system which forms part of the PDA shown in Figure 1. Figure 3 also illustrates the way in which the excitation winding and the sensor windings interact with the resonant stylus 5. In particular, Figure 3 schematically shows an excitation winding 29, two x-sensor windings 31 and 33 for sensing x position and two y-sensor windings 35 and 37 for sensing y position. Each of these windings is formed by printed

conductors on the sensor PCB 13. As will be explained in more detail below, the sensor windings 31, 33, 35 and 37 are periodic and are in spatial phase quadrature relative to each other. Therefore, in the following description x-sensor winding 31 will be referred to as the sin x sensor winding, x-sensor winding 33 will be referred to as the cos x sensor winding, y-sensor winding 35 will be referred to as the sin y sensor winding and y-sensor winding 37 will be referred to as the cos y sensor winding. As illustrated by the arrows 39, these windings are operable, in use, to couple magnetically with a resonant circuit 41 (comprising a capacitor 43 and an inductor coil 45) in the resonant stylus 5.

The excitation winding and the sensor windings are connected to digitiser electronics 49 (indicated by the dashed block in Figure 3) which generates an excitation signal which passes through the excitation winding 29 and determines an x-y position of the resonant stylus 5 from signals received from the sensor windings. The digitiser electronics 49 includes a digital processing and signal generation unit 59 which, in operation, generates control signals TXA and TXB for controlling an excitation driver 51 which applies an excitation voltage across the ends of the excitation winding 29. In this embodiment, the

excitation voltage applied across the ends of the excitation winding 29 comprises a sequence of positive and negative pulses having a fundamental frequency component (F_0) of approximately 100kHz, which is matched to the resonant frequency of the resonant circuit 41.

The excitation current flowing in the excitation winding 29 generates a corresponding electromagnetic field which magnetically couples, as indicated by the arrow 39-1, with the resonant circuit 41 and causes it to resonate. In this embodiment, the excitation winding 29 is arranged to keep the magnetic coupling between it and the resonator as constant as possible with the x-y position of the stylus relative to the LCD 3. When the resonator 41 is resonating, it generates its own electromagnetic field which magnetically couples, as represented by the arrows 39-2, 39-3, 39-4 and 39-5, with the sensor windings 31, 33, 35 and 37 respectively. As will be explained in more detail below, the sensor windings 31, 33, 35 and 37 are designed so that the coupling between them and the resonant stylus varies with the x or y position of the stylus and so that there is minimum direct coupling between them and the excitation winding 29. Therefore, the signal received in the sensor windings should only vary with the magnetic coupling

between the resonator 41 and the respective sensor winding. Consequently, by suitable processing of the signals received in the sensor windings, the x-y position of the resonator 41, and hence of the resonant stylus 5, can be determined relative to the sensor windings.

In this embodiment, in order to reduce the effect of any breakthrough from the excitation winding 29 to the sensor windings on the x-y position measurement, the excitation current is not continuously applied to the excitation winding 29 but instead bursts of the excitation current are applied, and the signals induced in the sensor windings are only detected between the bursts of the excitation current. This mode of operation is referred to as pulse echo and works because the resonator 41 continues to resonate after the burst of excitation current has ended.

As mentioned above, the sensor windings are periodic and are in spatial phase quadrature. Therefore, the four signals induced in the four sensor windings from the resonant circuit 41 can be approximated by:

$$E_{31} = Ae^{-t/\tau}\sin\left[\frac{2\pi x}{L_x}\right]\cos[2\pi F_o t + \phi] \qquad (1)$$

$$E_{33} = Ae^{-t/\tau}\cos\left[\frac{2\pi x}{L_x}\right]\cos[2\pi F_o t + \varnothing] \quad (2)$$

$$E_{35} = Ae^{-t/\tau}\sin\left[\frac{2\pi y}{L_y}\right]\cos[2\pi F_o t + \varnothing] \quad (3)$$

$$E_{37} = Ae^{-t/\tau}\cos\left[\frac{2\pi y}{L_y}\right]\cos[2\pi F_o t + \varnothing] \quad (4)$$

where A is a coupling coefficient which depends upon, among other things, the distance of the stylus from the windings and the number of turns in the sensor windings; x is the x-position of the resonant stylus relative to the sensor windings; y is the y-position of the resonant stylus relative to the sensor windings; L_x is a spatial wavelength of the sensor windings in the x-direction and is typically slightly greater than the width of the board in the x-direction (and in this embodiment is 70mm); L_y is a spatial wavelength of the sensor windings in the y-direction and is typically slighter greater than the width of the board in the y-direction (and in this embodiment is 50mm); $e^{-t/\tau}$ is the exponential decay of the resonator signal after the burst of excitation signal has ended, with τ being a resonator constant which is equal to the quality factor of the resonant circuit 41 divided by the product of pi (π) and the resonant frequency of

the resonant circuit 41; and ⌀ is an electrical phase shift caused by a difference between the fundamental frequency of the excitation current and the resonant frequency of the resonator 41. In this embodiment, the resonant stylus 5 is designed so that its resonant frequency changes with the pressure applied to the tip of the stylus. This change in frequency causes a change in the phase shift ⌀ and therefore by measuring the phase shift ⌀ it can be determined whether or not the tip of the resonant stylus 5 is pressed into contact with the LCD 3.

As can be seen from equations (1) to (4), the peak amplitude of the signals induced in the sensor windings vary as the sin or cos of either the x or y position. This is illustrated in Figures 4a and 4b. In particular, Figure 4a illustrates the way in which the peak amplitude of the signal induced in sensor winding 31 and the way in which the peak amplitude of the signal induced in sensor winding 33 varies with the x-position of the resonant stylus relative to the sensor windings and Figure 4b shows the way in which the peak amplitude of the signals induced in sensor winding 35 and sensor winding 37 vary with the y-position of the resonant stylus relative to the sensor windings. As shown in

Figure 4, the pitch (L_x) of the windings in the x-direction is greater than the pitch (L_y) of the windings in the y-direction. This is because, in this embodiment, the measurement area covered by the sensor windings is rectangular.

Therefore, as those skilled in the art will appreciate, both the x-y position information of the resonant stylus 5 and the phase shift ϕ can be determined from the signals induced in the sensor windings by suitable demodulation and processing. As shown in Figure 3, this demodulation is achieved by connecting each of the four sensor windings to a respective two of the eight mixers 69-1 to 69-8, where for each sensor winding the induced signal is multiplied by a square wave at the same frequency as and in phase with the excitation current in one of the respective mixers and is multiplied by a square wave signal at the same frequency as and 90° out of phase with the excitation current in the other of the respective mixers. This generates an in phase (I) component and a quadrature phase (Q) component of each of the demodulated signals. In this embodiment, the in phase components of the demodulated signals from all the sensor windings are used to determine the position information and the in phase and quadrature phase

components of the demodulated signal from one of the sensor windings are used to determine the electrical phase shift (i.e. ϕ). As shown in Figure 3, the output from each mixer 69-1 to 69-8 is input to a respective integrator 71-1 to 71-8 which, after being reset, integrates the output from the mixer over a time period which is a multiple of $1/F_0$ (in order to reduce the effect of error signals from the mixer at the fundamental frequency, for example clock feed-through). The following equations approximate the outputs from the integrators 71-1 to 71-4:

$$sin\_x\_I = A_1 \sin\left[\frac{2\pi x}{L_x}\right] \cos\phi \tag{5}$$

$$sin\_x\_Q = A_1 \sin\left[\frac{2\pi x}{L_x}\right] \sin\phi \tag{6}$$

$$cos\_x\_I = A_1 \cos\left[\frac{2\pi x}{L_x}\right] \cos\phi \tag{7}$$

$$cos\_x\_Q = A_1 \cos\left[\frac{2\pi x}{L_x}\right] \sin\phi \tag{8}$$

where A_1 is a constant which varies with, among other things, the constant A, the resonator constant τ and the

integration period. Similar signals are obtained from integrators 71-5 to 71-8, except these vary with the y-position rather than with the x-position.

As shown in Figure 3, the outputs from the integrators 71 are input to an analogue-to-digital converter 73 where they are converted into digital signals which are input to the digital processing and signal generation unit 59 via the A to D interface unit 75. The digital processing and signal generation unit 59 then performs an arc tangent function (atan 2) on the ratio of the sin_x_I signal and the cos_x_I signal to determine the x-position of the resonant stylus and similarly performs an arc tangent function on the ratio of the sin_y_I signal and the cos_y_I to determine the y-position of the resonant stylus 5. The digital processing and signal generation unit 59 also calculates an arc tangent function on the ratio of the quadrature phase component to the in phase component of the signals from one of the sensor windings, in order to determine the phase angle ø.

As shown in Figure 3, both the in phase (I) and quadrature phase (Q) components of the signal induced in each of the sensor windings are measured. This is because, at certain x and y positions, the ratio of the

in phase and quadrature phase components from the sensor windings will not be reliable. This occurs when the sin or cos position components are approximately zero. Therefore, in this embodiment, the digital processing and signal generation unit 59 determines the phase angle ∅ using a weighted combination of the in phase and quadrature phase signals from both the sin and cos windings, where the weighting used varies in dependence upon the determined x and y position of the stylus.

After the digital processing and signal generation unit 59 has determined the current x-y position of the resonant stylus and determined whether or not the stylus has been brought into contact with the LCD 3, it outputs this information to the PDA electronics through the interface unit 77. This information is then used by the PDA electronics to control information displayed on the LCD 3 and the PDA's mode of function. In this embodiment, the excitation and position determining circuitry 49 performs the above calculations five hundred times per second.

A brief description has been given above of the way in which the digitiser system of the present embodiment determines the x-y position of the resonant stylus

relative to the sensor windings. The particular form of excitation and sensor windings used and the particular resonant stylus used in this embodiment will now be described in more detail.

Digitiser Windings

The excitation winding 29 used in this embodiment is formed by five turns of rectangular conductor on each side of the sensor PCB 13 which are connected in series at through holes or vias. In this embodiment, the excitation winding 29 is wound around the outside of the sensor windings (not shown).

Figure 5a shows the printed conductors which form the sin x sensor winding 31. The printed conductors on the top layer of the sensor PCB 13 are shown as solid lines whilst those on the bottom layer are shown as dashed lines. As shown, the conductor tracks which extend substantially in the x-direction are provided on the top layer of the sensor PCB 13 and those which extend substantially in the y-direction are provided on the bottom layer of the sensor PCB 13 and the ends of the conductor tracks on the top layer are connected to the ends of the conductor tracks on the bottom layer at the via holes, some of which are labelled 97. Figure 5a also

shows the two connection pads 105 and 107 which are provided for connecting the sin x sensor winding 31 to the digitiser electronics.

The conductor tracks of the sin x sensor winding 31 are connected to form two sets of loops 32-1 and 32-2 which are arranged in succession along the x-direction, with each loop extending along the x-direction and being connected in series so that an electromotive force (EMF) induced in loops of the same set by a common background alternating magnetic field add together and so that EMFs induced in the first set of loops 32-1 by a common background alternating magnetic field oppose the EMFs induced in the second set of loops 32-2. As shown in Figure 5a, in this embodiment, there are four loops in each set of loops 32-1 and 32-2 and each set of loops is arranged to enclose a similar area. Therefore, any EMFs induced in the loops of the first set 32-1 by such a background magnetic field will substantially cancel out with the EMFs induced in the loops of the second set 32-2. However, as those skilled in the art will appreciate, if a point magnetic field source (or something similar such as the resonant stylus) is moved across the sensor winding 31 along the x-direction, then the magnetic coupling between the point source and the sensor winding

31 will vary with the x-position of the point source. As a result of the "figure-of-eight" connection between the two sets of loops 32-1 and 32-2, this variation with x-position can be approximated to be sinusoidal. As those skilled in the art will appreciate, it is because of this approximate sinusoidal variation that the signal induced in the sensor winding 31 by the resonant stylus 5 has a peak amplitude which approximately varies as the sine of the x-position of the stylus 5 relative to the sensor windings.

Figure 5b shows the printed conductors which form the cos x sensor winding 33. Again, the printed conductors on the top layer of the sensor PCB 13 are shown as solid lines whilst those in the bottom layer as shown as dashed lines. As with the sin x sensor winding 31, most of the conductor tracks which extend in the x-direction are provided on the top layer of the sensor PCB 13 and most of those which extend in the y-direction are provided on the bottom layer of the sensor PCB 13 and the ends of the conductor tracks on the top layer are connected to the ends of the conductor tracks on the bottom layer at the via holes, some of which are labelled 97. Figure 5b also shows the two connection pads 109 and 111 which are provided for connecting the cos x sensor winding 33 to

the digitiser electronics.

The conductor tracks of the cos x sensor winding 33 are connected to form three sets of loops 34-1a, 34-2 and 34-1b which are arranged in succession along the x-direction, with each loop extending along the x-direction and connected in series so that an EMF induced in loops of the same set by a common background alternating magnetic field add together and so that EMFs induced in the first and third set of loops 34-1a and 34-1b by a common background alternating magnetic field oppose the EMFs induced in the second set of loops 34-2. As with the sin x winding, there are four loops in each set of loops and the loops in the second set of loops are arranged to enclose a similar area to the combined area enclosed by the loops in the first and third set of loops. As a result, EMFs induced in the loops by a background magnetic field will substantially cancel out with each other. However, as with the sin x sensor winding, when the resonant stylus 5 is moved across the sensor winding 33 along the x-direction, the magnetic coupling between the resonant stylus 5 and the cos x sensor winding 33 varies with the x-position of the stylus 5. As a result of the alternating sense of conductor loops, this variation with x-position can be

approximated to be sinusoidal. However, since the sets of loops of the cos x sensor winding 33 are shifted in the x-direction by a quarter of the winding pitch (L_x), the sinusoidal variation will be in phase quadrature to the variation of the sin x sensor winding 31. As a result, the signal induced in the sensor winding 33 by the resonant stylus 5 has a peak amplitude which approximately varies as the cosine of the x-position of the stylus 5 relative to the sensor windings.

Figures 5c and 5d show the printed conductors which form the sin y sensor winding 35 and the cos y sensor winding 37. As shown in these figures, these sensor windings are similar to the sin x and cos x sensor windings except they are rotated through 90°. As shown in Figures 5c and 5d, the sin y sensor winding 35 shares the connection pad 107 with the sin x sensor winding 31 and the cos y sensor winding 37 shares the connection pad 111 with the cos x sensor winding 33. The other ends of the sin y and cos y sensor windings are connected to connection pads 113 and 115 respectively. Figure 5e shows the top layer of printed conductors and Figure 5f shows the bottom layer of printed conductors of the sensor PCB 13, which together form the excitation winding 29 and the sensor windings 31, 33, 35 and 37. In the circuit board shown

in Figure 5, the conductor tracks have a width of approximately 0.15mm and the minimum gap between adjacent tracks is approximately the same. Although it is possible to employ finer tracks and gap distances on the PCB, this increases cost due to additional manufacturing precision and lower manufacturing yields.

Design of Sensor Windings

As those skilled in the art will appreciate, the design of the sensor windings is one of the most critical aspects of the digitiser. The design involves, for a given area of printed circuit board, maximising the digitising area and the accuracy of and the signal levels from the sensor windings. As will be apparent to those skilled in the art, the critical aspect of the x-direction sensor windings 31 and 33 are the x-positions of the conductor tracks of the windings 31 and 33 which extend in the y-direction. Similarly, the critical aspect of the design of the y-position sensor windings 35 and 37 is the y-position of the conductor tracks of the windings 35 and 37 which extend in the x-direction. In the following discussion, these conductors will be referred to as the primary sensing conductors and the tracks which connect the ends of these primary sensing conductors to other primary sensing conductors will be

referred to as the connecting conductors. For illustration, some of the primary sensing conductors are indicated by reference numerals 31-p, 33-p, 35-p and 37-p and some of the connecting conductors are indicated by reference numerals 31-c, 33-c, 35-c and 37-c in Figures 5a to 5d.

As can be seen from Figures 5a to 5d, the most striking feature of most of the primary sensing conductors is their irregular form with multiple bends or kinks as they extend from one side of the sensor board to the other. In all prior art systems that the applicant is aware of, these primary sensor windings are formed by straight parallel lines. However, the applicant has found that the use of such irregular shaped primary sensing conductors can result in more accurate position sensing by the digitiser electronics.

The reason that these irregular primary sensing conductors can provide accurate position sensing is that positional errors caused by irregularities or bends of the primary sensing conductors of the sine winding can be compensated by complementary irregularities or bends in the primary sensor windings of the cosine winding. These errors then cancel with each other when the arc

tangent function is calculated by the digitiser electronics, thereby giving a more accurate position measurement.

There are various ways in which the design of the sensor windings shown in Figures 5a to 5d can be made. For example, the position and direction of each of the primary sensing conductors may be manually changed using an iterative trial and error technique until an appropriate design is found which provides the required position sensing accuracy. However, as those skilled in the art will appreciate, such a manual trial and error technique would be highly time-consuming and computer-assisted optimisation techniques can be used to assist in the design of the windings. In order to work, such a computer-assisted system would have to include a mathematical model of the physical interaction between at least the resonator and the sensor windings and the processing performed by the electronics. In this embodiment, the model would also preferably include details of the interaction between the excitation winding and the sensor windings so that the design of the sensor windings can be chosen to minimise the direct coupling with the excitation winding. An initial starting point design would be provided (such as the design of the

windings described in the applicant's earlier international application WO 00/33244) with the objective of the optimisation being to vary the position of at least the primary sensing conductors in order to maximise the position sensing accuracy of the sensor over the entire measurement area. Various constraints may be provided in order to constrain the "solutions" provided by the computer system. For example, a limit may be placed on the number of vias that can be used or different tolerances of position sensing accuracy may be defined for different regions of the sensor board (such as requiring more accurate position sensing in the centre of the board than at the edges or corners of the sensor board).

Stylus

Figure 6 shows the resonant stylus 5 used in this embodiment in cross-section. As shown, the stylus comprises a hollow front body portion 152 and a hollow rear body portion 154 which house: the resonant circuit comprising the inductor coil 45 and the capacitor 43 (not shown); a 2mm diameter ferrite rod 153; a first movement-limiting member 155; a second movement-limiting member 157; a nib 159; and a spring 163. A more detailed description of the stylus used in this embodiment can be

found in International Patent Application No. WO 00/33244.

Modifications and Alternative Embodiments

A number of modifications and alternative embodiments will now be described.

In the above embodiment, two phase quadrature sensor windings were provided for use in a two-dimensional digitising system. As those skilled in the art will appreciate, the windings described above may be used in one-dimensional or three-dimensional position sensing systems. Further, instead of having two phase quadrature windings for each measurement direction, three or more sensor windings may be provided spatially offset from each other along the measurement direction, provided the signals from these sensor windings can be combined electrically to resolve the cyclic ambiguity associated with one sensor winding.

In the above embodiment, the resonant stylus was energised by applying an excitation current to an excitation winding. In response, the resonant stylus induced signals in the sensor windings from which the position of the stylus relative to the windings was

determined. As those skilled in the art will appreciate, the system may be arranged to operate in reverse so that the excitation signal can be applied (in turn) to the sensor windings which energise the resonator which in turn induces the signals into the excitation winding. Alternatively still, it is possible to both energise the resonator and to detect signals from the resonator using sensor windings like those described in the first embodiment. The way in which this can be achieved is described in the applicant's earlier international application WO 98/58237, the contents of which are incorporated herein by reference.

In the above embodiment, most of the primary sensing conductors of each phase quadrature sensor winding have an irregular form with multiple bends along their length. As those skilled in the art will appreciate, this is not essential. In an alternative embodiment one of the phase quadrature windings may be a conventional type of winding having substantially parallel primary sensing conductors (such as those described in WO 00/33244), with the primary sensing conductors of the other phase quadrature winding having multiple bends along their length which are designed to compensate for the positional errors of the conventional winding.

In the above embodiment, sensor windings were used which were designed to have an approximate sinusoidal coupling with the resonant stylus, as a result of which the signals output from the sensor windings varied approximately sinusoidally with the position of the stylus relative to the windings. As those skilled in the art will appreciate, the approach taken to the design of the sensor windings is not limited to such "sinusoidal" windings. The technique can be used on any windings which produce an output signal which varies in a non-monotonic fashion with the position to be measured and in which two or more of such sensor windings are used to resolve the ambiguity caused by this non-monotonic characteristic of the windings by appropriate processing of the sensor signals by the processing electronics.

As those skilled in the art will appreciate, the digitising system described above can be used for various applications. It is particularly useful, however, for low cost high volume consumer products such as PDAs, web browsers and mobile telephones and the like. Figure 7 illustrates the way in which a mobile telephone 251 may be adapted to include a liquid crystal display 255 and underneath the display an x-y set of digitiser windings such as those described above which are operable to sense

the position of a resonant stylus 257. The digitising system may be used to allow the user to create, for example, short text messages which can then be sent by the mobile telephone to another party. If the mobile telephone includes, for example, an organiser, then the digitiser can be used to control the inputting, manipulation and outputting of data from the organiser.

In the above embodiments, the digitiser system employed a number of sensor windings, an excitation winding and a resonant stylus. In an alternative embodiment, rather than using a resonant stylus, a stylus having either a short-circuit coil or a magnetic field concentrator (such as a piece of ferrite) could be used. However, in such embodiments, lower signal levels would be induced in the sensor windings and the system could not operate in the pulse-echo mode of operation since the non-resonant elements do not continue to "ring" after the excitation signal has ended. The techniques described above are equally applicable to position sensors having styluses which contain an active device in addition to or instead of the resonant circuit, such as the stylus described in US Patent No. 5,600,105. Indeed when a powered stylus is used there is no need for an excitation winding to energise the stylus.

In the above embodiment, the circuitry for analysing the signals induced in the sensor windings in the above-described examples used mixers and integrators. Alternatively an analog-to-digital converter can be used to directly digitise the induced signals and a digital processor can be used to determine the pen position from, for example, the amplitudes and phases of the induced signals. Alternatively, an analogue processing scheme, such as that described in International Patent Application No. WO99/34171, could be utilised to determine the position of the stylus.

The skilled person will recognise that the sensor windings described above can be applied to other forms of position sensors. For example, the position sensor may measure position in one dimension, which can be either linear or rotary. Alternatively, the position sensor may measure position in six dimensions, namely x, y, z, yaw, pitch and roll.

In the above embodiments a resonant stylus 5 was used to couple energy from the excitation winding to the sensor winding. In alternative embodiments, the relative position of a first member carrying an excitation winding and a second member carrying a sensor winding can be

determined by energising the excitation winding and detecting a signal induced in the sensor winding through coupling of electromagnetic energy.

CLAIMS:

1. A position sensor including:

first and second members which are relatively movable along a measuring path, the first member carrying a transmitter which, in use, is electromagnetically coupled to a receiver carried by the other member, which transmitter and receiver are arranged so that in response to the transmission of a signal by said transmitter, there is induced in said receiver first and second output signals which vary with the relative position of the first and second members along said measuring path; and

means for determining the relative position of the first and second members along said measured path as a predetermined function of said first and second output signals;

wherein at least one of the transmitter and receiver comprises first and second circuits, each circuit having a plurality of primary sensing conductors which are separated from each other along said path, which cross said path and which are connected together to form at least one loop; and

wherein one or more of said primary sensing conductors of said first circuit have multiple bends whose positions are determined in order to compensate for

position errors caused by the position of the primary sensing conductors of the second circuit through the operation of said predetermined function on said first and second output signals.

2. A position sensor according to claim 1, wherein one or more of said primary sensing conductors of each of said first and second circuits have multiple bends whose positions are determined in order to compensate for position errors caused by the position of the primary sensing conductors of the other circuit through the operation of said predetermined function on said first and second output signals.

3. A position sensor according to claim 1 or 2, wherein said primary sensing conductors are connected together to form at least two loops which are arranged along said measuring path and which are connected in series and arranged so that EMFs induced in adjacent loops by a common background alternating magnetic field oppose each other.

4. A position sensor according to any preceding claim, wherein the at least one loop of said second circuit is spatially separated along said measuring path from the

at least one loop of said first circuit.

5. A position sensor according to claim 4, wherein said at least one loop of said second circuit is spatially separated along said measuring path by half the extent of the at least one loop of said first circuit.

6. A position sensor according to any preceding claim, wherein said primary sensing conductors are connected together to form at least one set of loops which are connected in series and arranged so that EMFs induced in loops of the same set by a common alternating magnetic field add together.

7. A position sensor according to any preceding claim, wherein said transmitter comprises an electromagnetic device and wherein said second member comprises an excitation circuit for energising the electromagnetic device.

8. A position sensor according to claim 7, wherein said electromagnetic device comprises an electromagnetic resonator.

9. A position sensor according to claim 7 or claim 8,

further comprising drive means for applying an input driving signal to said excitation circuit.

10. A position sensor according to claim 9, wherein said drive means is operable to apply a pulse of said driving signal during a first time interval and wherein said determining means is operable to determine the relative position of said first and second members from said first and second signals induced in said receiver during a second time interval after the first time interval.

11. A position sensor according to any preceding claim, wherein said predetermined function includes a ratio calculation of the first and second output signals.

12. A position sensor according to claim 11, wherein said predetermined function includes a trigonometric ratio calculation of the first and second output signals.

13. A position sensor according to any preceding claim, wherein said receiver comprises said first and second circuits.

14. A position sensor according to claim 13, wherein said primary sensing conductors are carried on a planar

surface of said second member.

15. A position sensor according to claim 14, wherein said transmitter comprises a coil whose axis is generally perpendicular to said planar surface of said second member.

16. A position sensor according to any of claims 1 to 12, wherein said transmitter comprises said first and second circuits.

17. A position sensor according to any preceding claim, wherein said second member is fixed and wherein said first member is movable with respect to said second member.

18. A position sensor according to any preceding claim, wherein said measuring path is linear.

19. A position sensor according to any preceding claim, wherein said at least one of said transmitter and receiver further comprises third and fourth circuits, each having a plurality of primary sensing conductors which are separated from each other along a second measuring path which is substantially orthogonal to the

other measuring path, whereby said position sensor is operable to determine the relative position of said first and second members in two dimensions.

20. A position sensor according to any of claims 1 to 17, wherein said measuring path is curved.

21. A position sensor according to any preceding claim, wherein said primary sensing conductors are connected together to form at least two sets of loops arranged along said path, each loop extending along said path and said loops being connected in series and being arranged so that EMFs induced in loops of the same set by a common alternating magnetic field add together and so that EMFs induced in the first set of loops by a common alternating magnetic field oppose the EMFs induced in the second set of loops.

22. A position sensor according to claim 21, wherein each set of loops comprises the same number of loops.

23. A position sensor according to claim 21 or 22, wherein each set of loops is arranged to enclose substantially the same area.

24. A position sensor according to any preceding claim, wherein said first and second circuits are formed as conductive tracks on a printed circuit board.

25. A position sensor according to claim 24, wherein said printed circuit board is a two-layer printed circuit board.

26. A position sensor according to claim 24 or 25, wherein said printed circuit board is a flexible printed circuit board.

27. A position sensing method characterised by the use of a position sensor according to any of claims 1 to 26.

ABSTRACT

POSITION SENSOR

An x-y digitising system is provided for use in consumer electronic devices, such as portable digital assistants, mobile telephones, web browsers and the like. The digitizer includes a resonant stylus, an excitation winding for energising the resonant stylus and a set of sensor windings for sensing a signal generated by the stylus, from which the x-y position of the stylus is determined.

FIG. 1

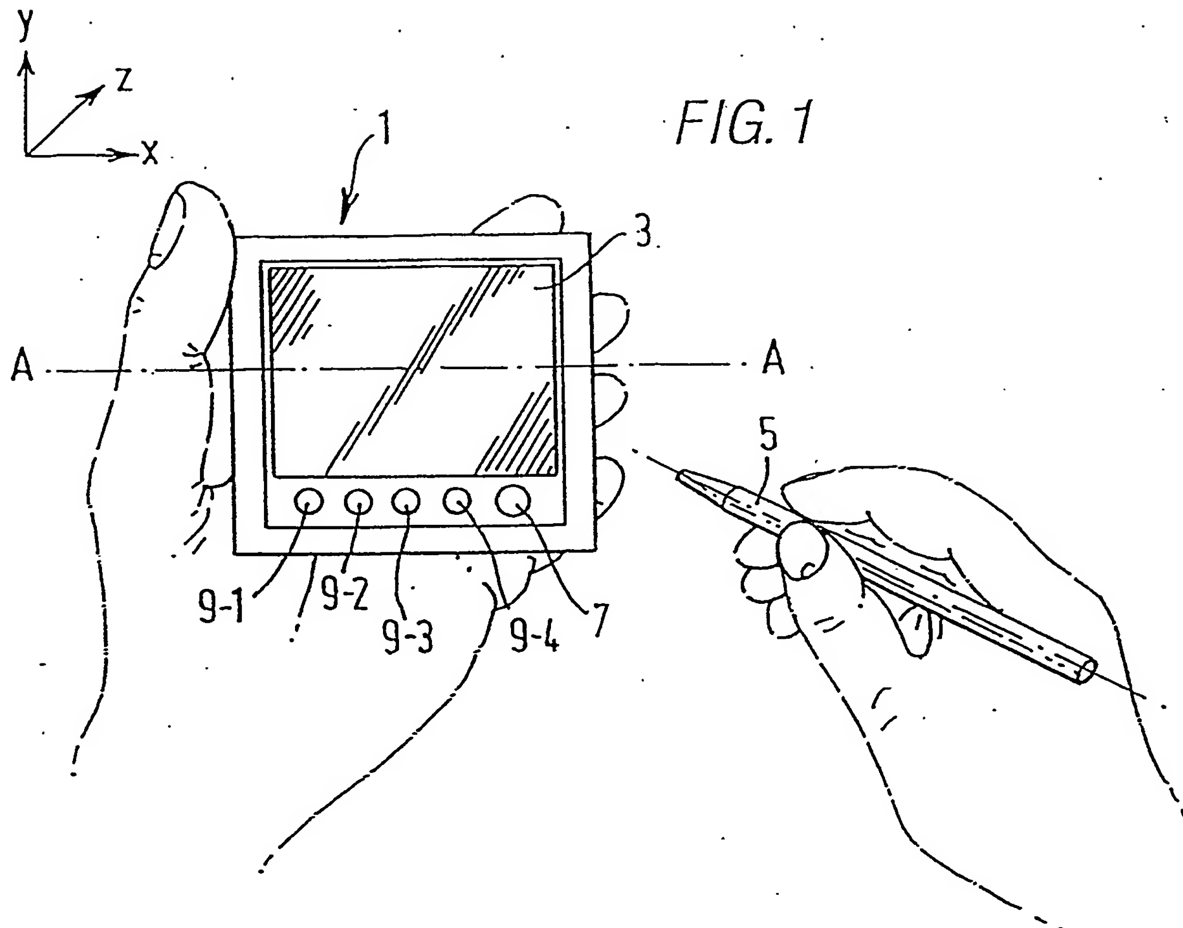


FIG. 2

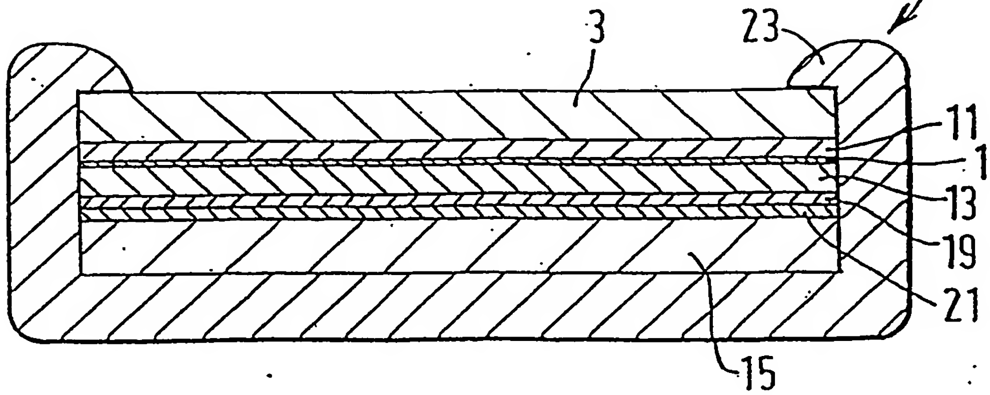
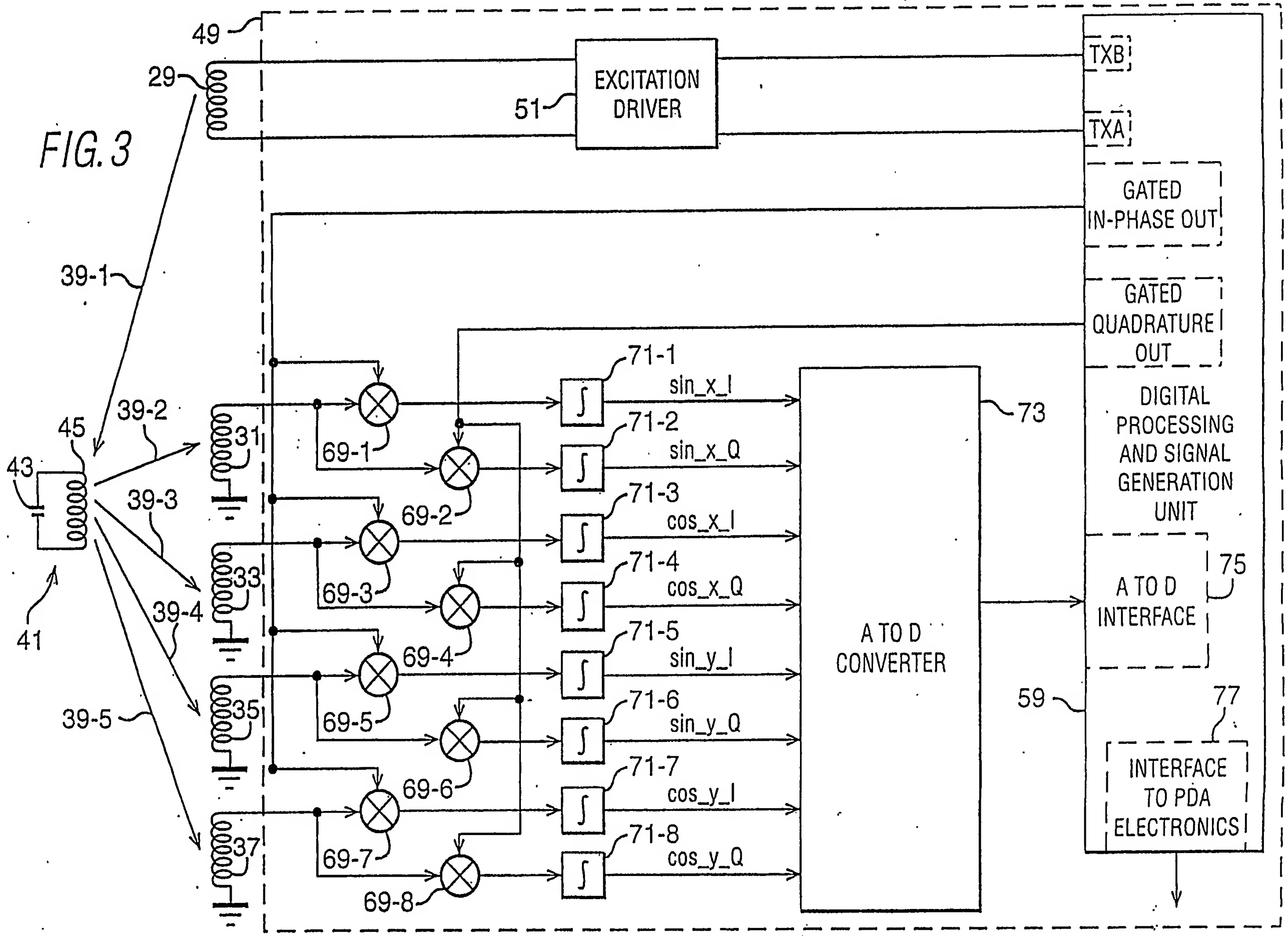


FIG. 3



49
29
51
EXCITATION DRIVER
TXB
TXA
GATED IN-PHASE OUT
GATED QUADRATURE OUT
DIGITAL PROCESSING AND SIGNAL GENERATION UNIT
A TO D INTERFACE
75
59
INTERFACE TO PDA ELECTRONICS
77
A TO D CONVERTER
73
39-1
39-2
39-3
39-4
39-5
41
43
45
31
33
35
37
69-1
69-2
69-3
69-4
69-5
69-6
69-7
69-8
71-1
71-2
71-3
71-4
71-5
71-6
71-7
71-8
sin_x_I
sin_x_Q
cos_x_I
cos_x_Q
sin_y_I
sin_y_Q
cos_y_I
cos_y_Q

FIG. 4a

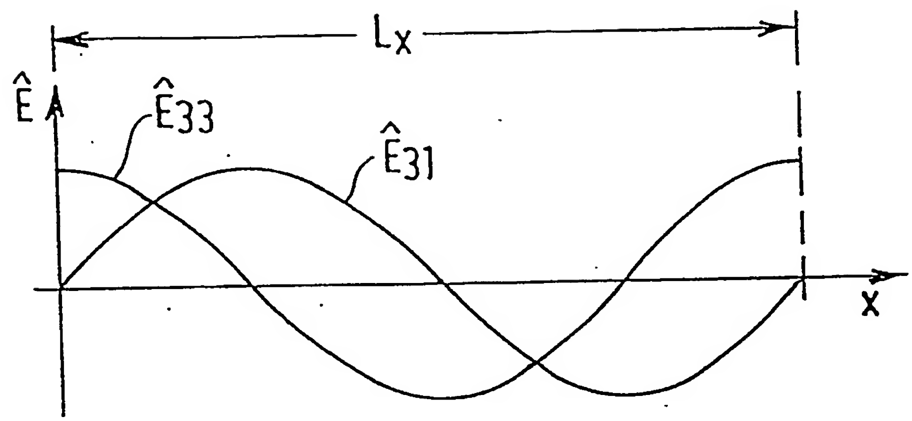
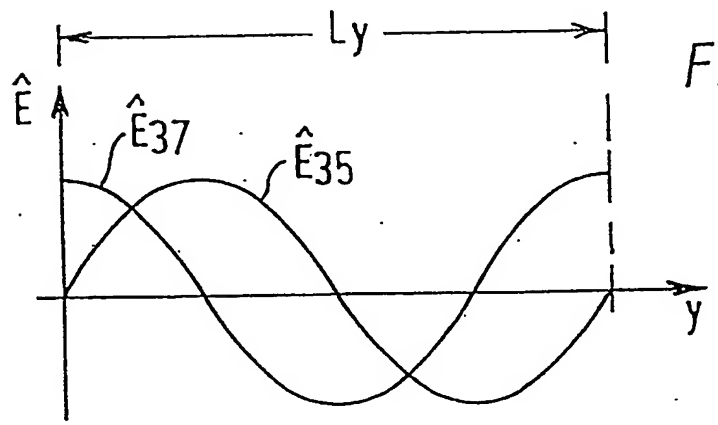


FIG. 4b



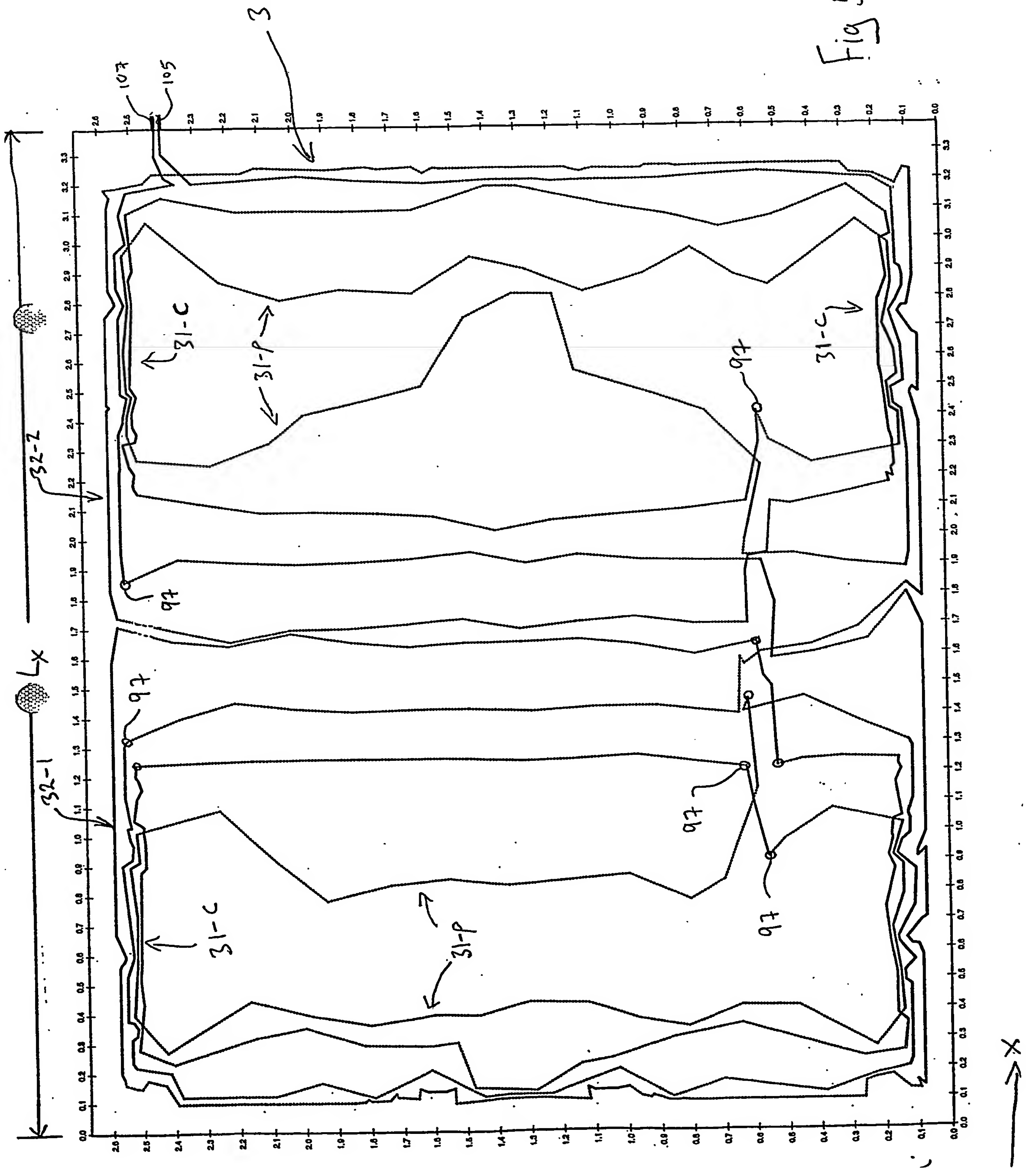


Fig 5a

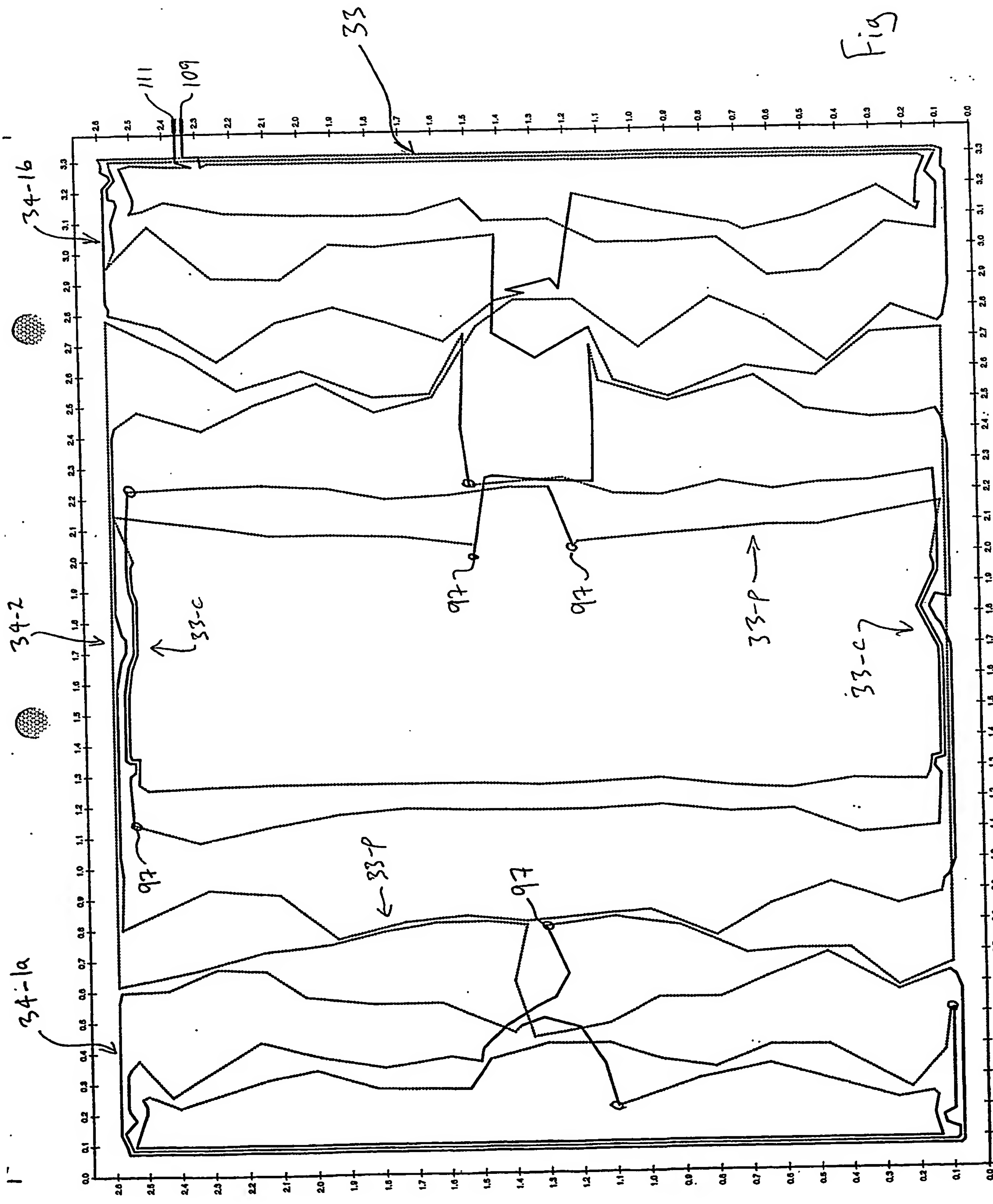


Fig 5b

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Fig 5c

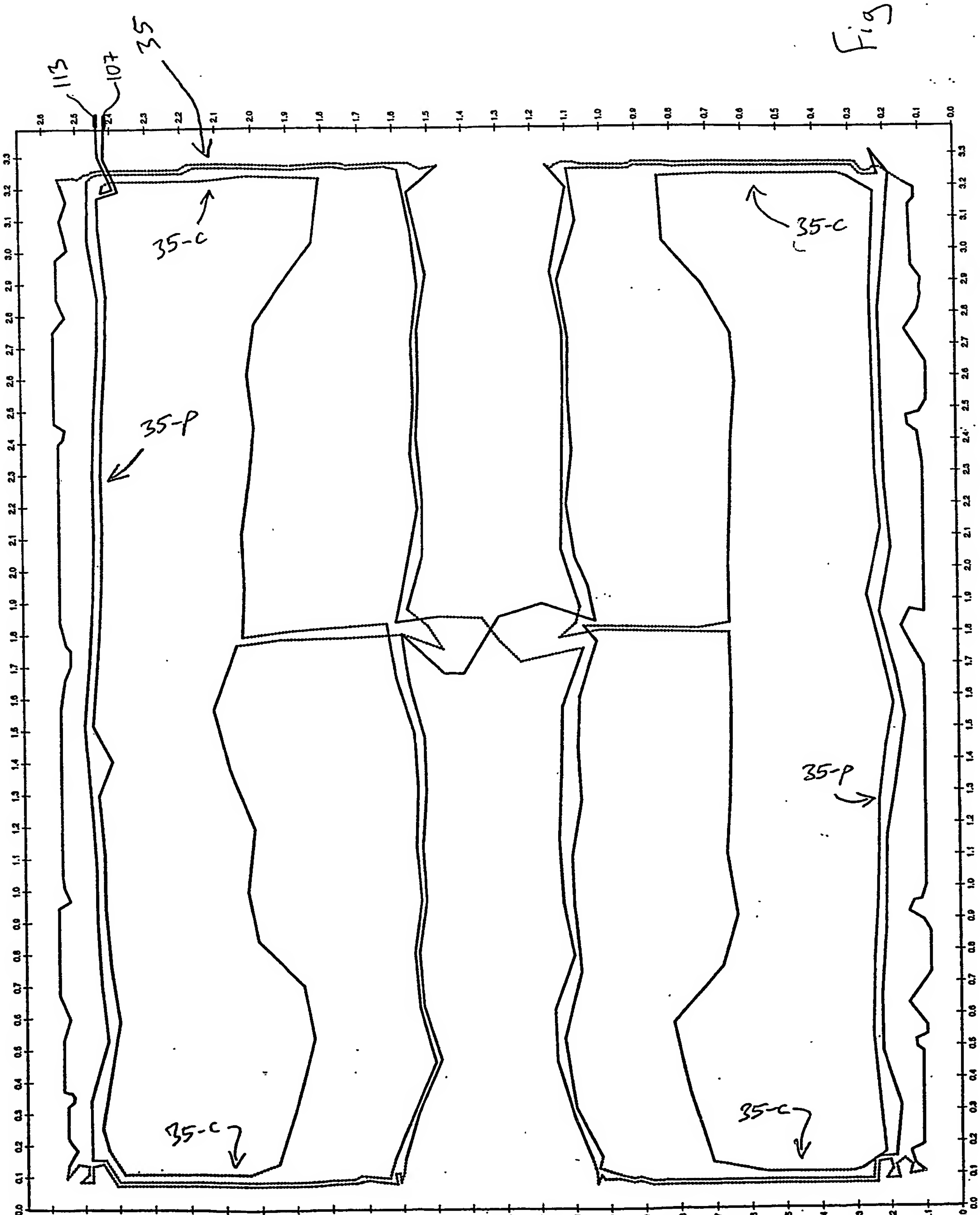

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Fig 5d

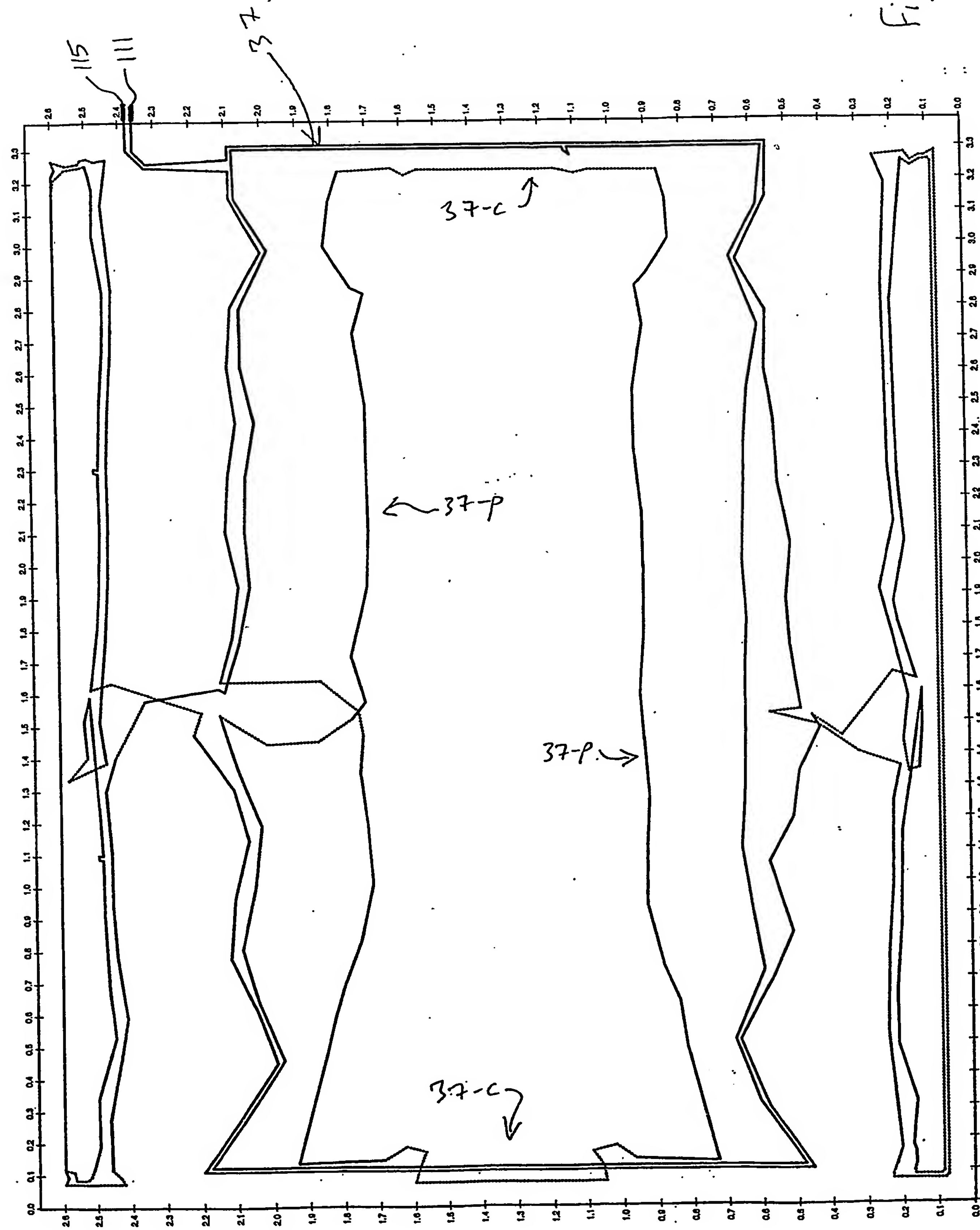

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Fig. 5e

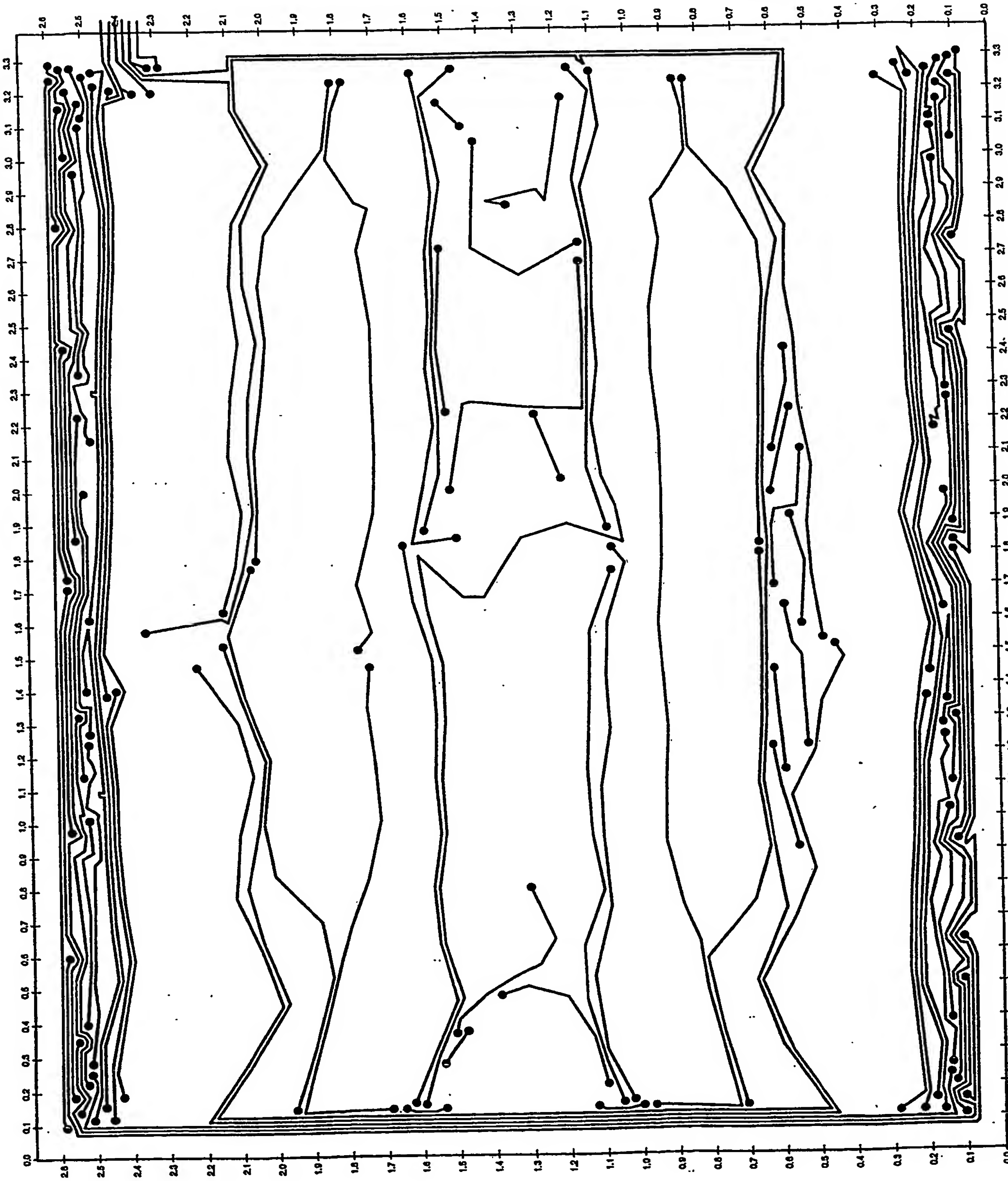

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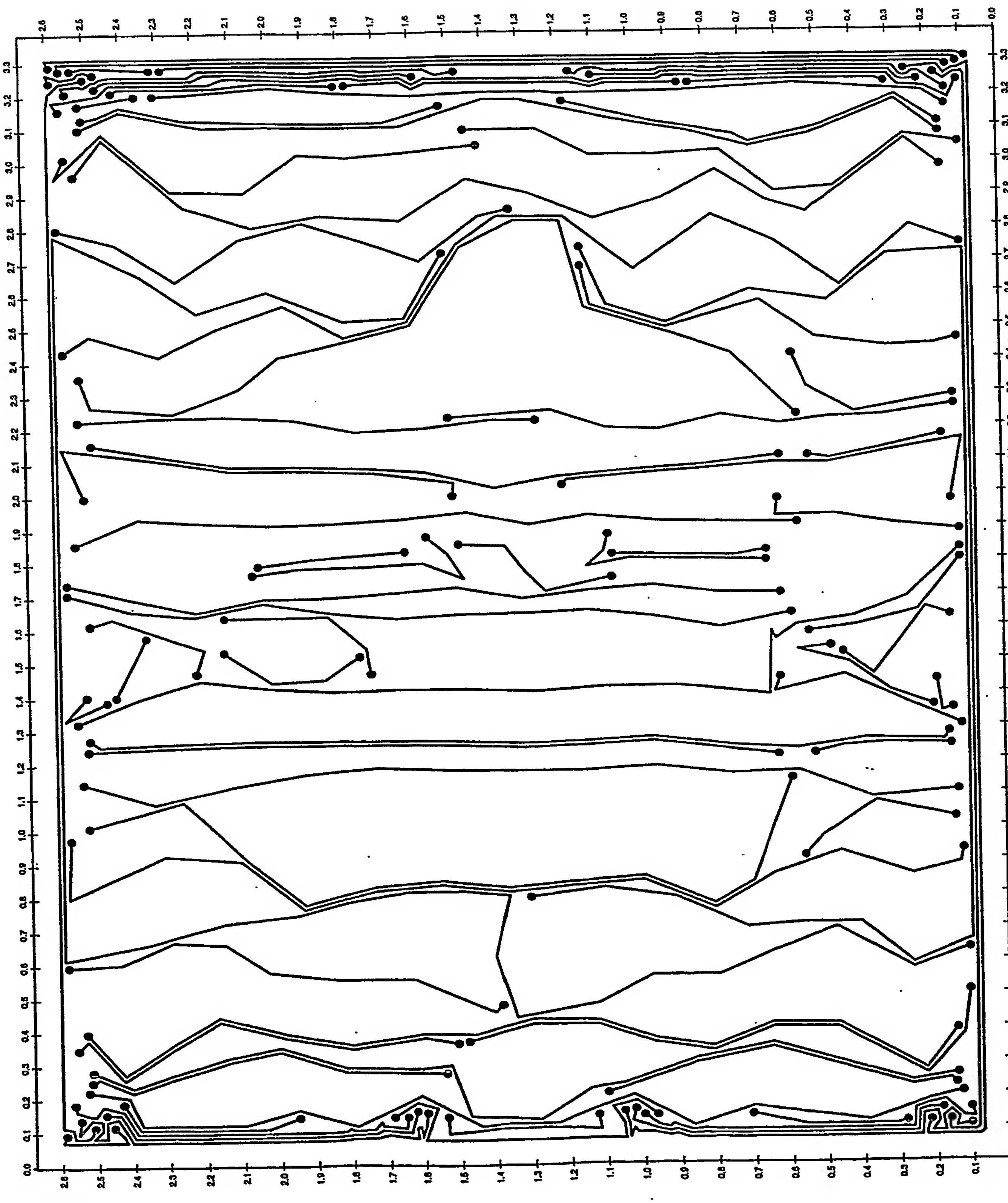
Fig 5f



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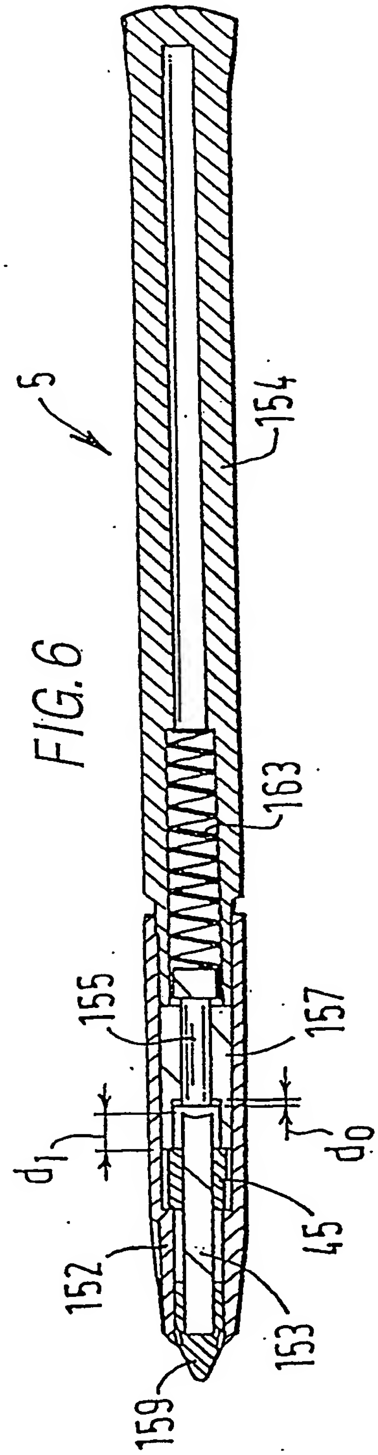
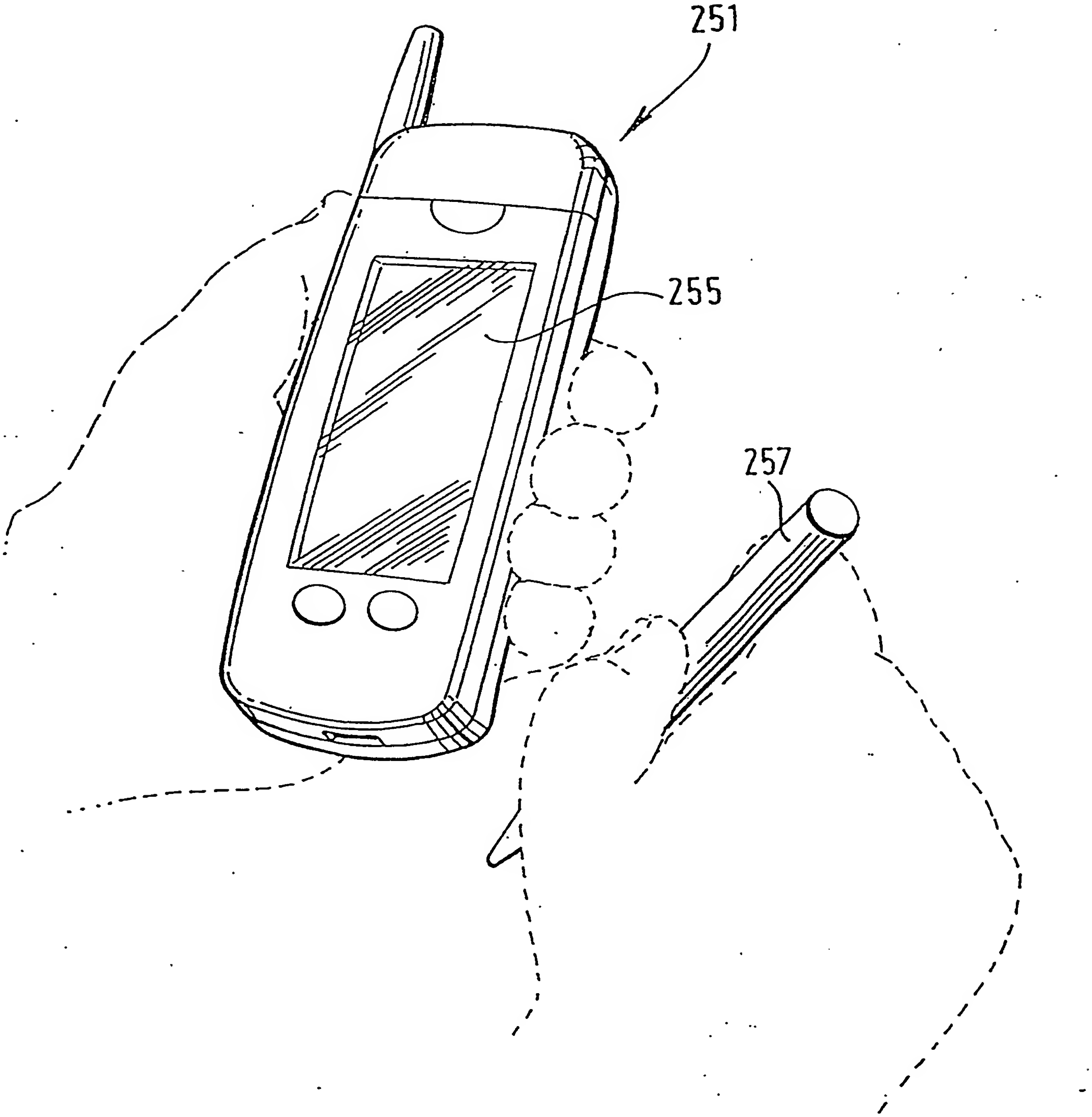


FIG. 6

FIG. 7



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